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Elutriation of flotation products

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ELUTRIATION OF FLOTATION PRODUCTS.

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A

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I L L U S T R A T I O N S .

P R E F A C E .

This thesis contains the results of an investigation carried on at the Mississippi Valley Experimental Station of the U.S.Bureau of Mines, Department of Commerce, in cooperation with the School of Mines and Metallurgy, Rolla, Mo. to study flotation products with particular reference to grain size and mineral distribution.

A C K N O W L E D G M E N T S .

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PURPOSE OF INVESTIGATION.

Since the first application of the flotation process in ore dressing practice, engineers have been busy solving the most delicate relations of metal distribution in the minerals to be treated.

A common method of investigating mill products is to divide the material into fractions of different grain sizes by means of a series of screens. Besides others of less importance, the well known Tyler Standard Screen Scale has been developed, in which the products are screened so that the successive sizes have a diameter of the square root of two. The number of meshes of the finest sieve has been limited by the technical difficulties in manufacturing with reasonable accuracy screens with very small openings. But with the development of the machinery for making very fine wire cloth, the lower limit of screening has changed gradually to greater fineness.

While in about 1913 an accurate 200 mesh screen could hardly be made, and 150 mesh was considered as the limit of screen analysis, within the next ten years the manufacture of 200 and 270 mesh and even of 325 mesh screens of sufficient accuracy was accomplished. Recently even a screen of 400 mesh per linear inch has been made, and it has been used for this work.

As a consequence of this slow development we find in the current literature most of the screen analyses done down to 200 or 325 mesh, the finest material being termed as "minus 200 mesh" or "minus 325 mesh". Little attention seems to have been paid to the composition and mineral distribution within the particles of these finest materials.

Further investigation of flotation concentrates is of course of little interest to the mill operator as long as his plant is running with good efficiency. When the results of concentration are insufficient, or the flow sheet must be changed for other reasons, more attention has to be paid to the products as regards their special composition. Examinations in this direction have shown, for example, that in the tailing from a galena flotation process the lead content generally increases with decreasing size of the slime particles and that the product "minus 200 mesh" or "minus 325 mesh" assays highest in lead. However, on account of the lack of a suitable means of separating the material into fractions containing the various sized grains we are too easily inclined to consider slime as a definite product.

Modern technical literature contains only very few data dealing with careful examinations of those products which are out of the range of ordinary screening. Of

little importance are notes of microscopic measurements of the particles in a minus 200 mesh sample and rough estimations of the percentages of the different grain sizes.

The desire for more information was the reason for research concerning the mineral distribution in fine flotation material with particular attention to the development of a suitable laboratory method of hydraulic classification or, as it is especially called, elutriation.

THEORY OF THE ELUTRIATION PROCESS.

Elutriation is a sizing process using an upward rising water current. While sizing by screening is dependent upon the diameter and only to a small extent upon the shape of the particles, in this process the density, shape, and size of the particles, and viscosity and temperature of the fluid are all important factors influencing more or less what is called the "hydraulic value". The hydraulic value is the rate of vertical flow of water expressed in cc./sec. necessary to keep the particle in suspension in a definite elutriator; i.e.,

$$\text{Hydraulic Value} = \frac{\text{Overflow per Second in cc.}}{\text{Cross-Sectional Area of Elutriator in cm}^2}.$$

Hence elutriation is a method of dividing finely ground products into groups each having a definite hydraulic value.

In order to give a better picture of what hydraulic value means and by what laws it is determined, a short discussion of the principles of hydraulic classification follows.

Two different conditions under which settling takes place may be distinguished:

(1) Free Settling occurs where individual particles fall freely against an opposing upward current, without being hindered by other particles.

(2) Hindered Settling takes place where particles of mixed sizes, shapes, and gravities in a crowded mass, yet free to move among themselves, are sorted in a rising current of water, the velocity of which is much less than the free falling velocity of the particles, but yet enough, so that the particles are in motion.

Richards, R.H., Ore Dressing. 1908. McGraw-Hill Book Co, Chapter XII. Laws of Classifying by Free Settling in Water.

The most important factor which permits comparison of both laws is the terminal velocity which a mineral particle attains under the effect of either of the laws.

The first case, free fall in water, studied first by Rittinger, considers the friction between particles and medium to be small as compared with the dynamic effect or

eddying resistance of the current. The terminal velocity is expressed by the formula

$$v_0 = \sqrt{2gD(\delta-1)}$$
$$= C\sqrt{D(\delta-1)}$$

where C is a constant depending on the character of the material, D the diameter of the mineral grain, and δ is the specific gravity of the particle.

In order to find out if this formula holds for the elutriation of the material of the fineness to be discussed, the equation is written as follows:

$$C = \frac{v_0}{\sqrt{D(\delta-1)}}$$

and C is calculated for different values of D and v_0. The values of v_0 were found by practical elutriation of pure quartz (Ottawa) sand with a density of δ = 2.65. Since C is a constant one must get, if Rittinger's theory is correct, for C an approximate constant value throughout all grain sizes.

$$C = \frac{v_0}{\sqrt{Dx1.65}}$$

The results of such a test gave, for

1.	v_0 = .112 mm/sec.	C =	.841
2.	= .180 "	=	1.033
3.	= .500 "	=	2.44
4.	=1.43 "	=	5.62
5.	=3.15 "	=	10.12
6.	=6.40 "	=	18.3

The results obtained show that the values for C are not constant, but increase with increasing hydraulic values. Therefore Rittinger's Law cannot cover the conditions under which the elutriation of such fine material takes place.

The only explanation is that the particles are so fine that their classification has to be determined by the rules of "hindered settling". And indeed, the following results will prove that the law which takes into account hindered settling, covers fairly well the range of slime elutriation. This law of "viscous resistance", as it is often named, is determined correctly enough by Stokes' formula (uncorrected) for the terminal velocity of small roundish bodies, settling at such slow velocities, that the eddying resistance (Rittinger's Law) can be neglected.

Stokes' formula is as follows:

$$v_0 = \frac{2 \times g \, (\delta - 1) \, D^2}{9 \times \eta \times 4}$$

In this formula

gravity constant $g = 981$ cm/sec./sec.

viscosity factor $\eta = .01$ gm/cm x sec. (for water at $20^{\circ}C$)

Density of particles in gm/cm^3.

diameter of particles D in cm.

terminal velocity v_0 in cm/sec.

Since the terminal velocity and the diameters of the

elutriated particles are very small, we determine D in mm and get v_0 in mm/sec.

$$v_0 = \frac{2 \times 981 \, (\delta - 1) \, D^2}{9 \times .01 \times 4 \times 10}$$

$$v_0 = 545 \, (\delta - 1) \, D^2 \text{ mm/sec.}$$

$$\underline{v_0 = 900 \, D^2} \text{ (for pure quartz)}$$

In order to find out wether or not Stokes' Law gives correct values in the range of this investigation, first of all an "ideal" elutriation test with metal-free quartz sand was considered.

The following Table I shows the ideal results. The Tyler scale was continued (approx.) below the 400 mesh limit down to 1.7 micron, and to these particle sizes, the corresponding hydraulic values were determined by Stokes' formula for a density of $\delta = 2.65$.

When the results of this ideal elutriation are represented graphically in such a manner that the logarithms of v_0 are plotted as ordinates against the logarithms of D as abscissae the resulting curve must be a straight line as shown in Fig. 1.

To check this curve by practical results an elutriation of a small sample (10 gm) of ground sand was performed. The residues were microscopically examined and a representative diameter of each group determined as described previously.

Table I.

Ideal values according to Stokes ' Law.

Mesh	D in mm	D^2 in mm^2	v_o in mm/sec.
100	.147	.021 609	19.448
150	.104	.010 816	9.734
200	.074	.005 476	4.928
270	.053	.002 809	2.528
400	.038	.001 444	1.300
	.027	.000 702	.632
	.019	.000 361	.325
	.013	.000 169	.152
	.009	.000 090	.081
	.007	.000 042	.038
	.005	.000 023	.021
	.003	.000 011	.010
	.0024	.000 006	.005
	.0017	.000 003	.003

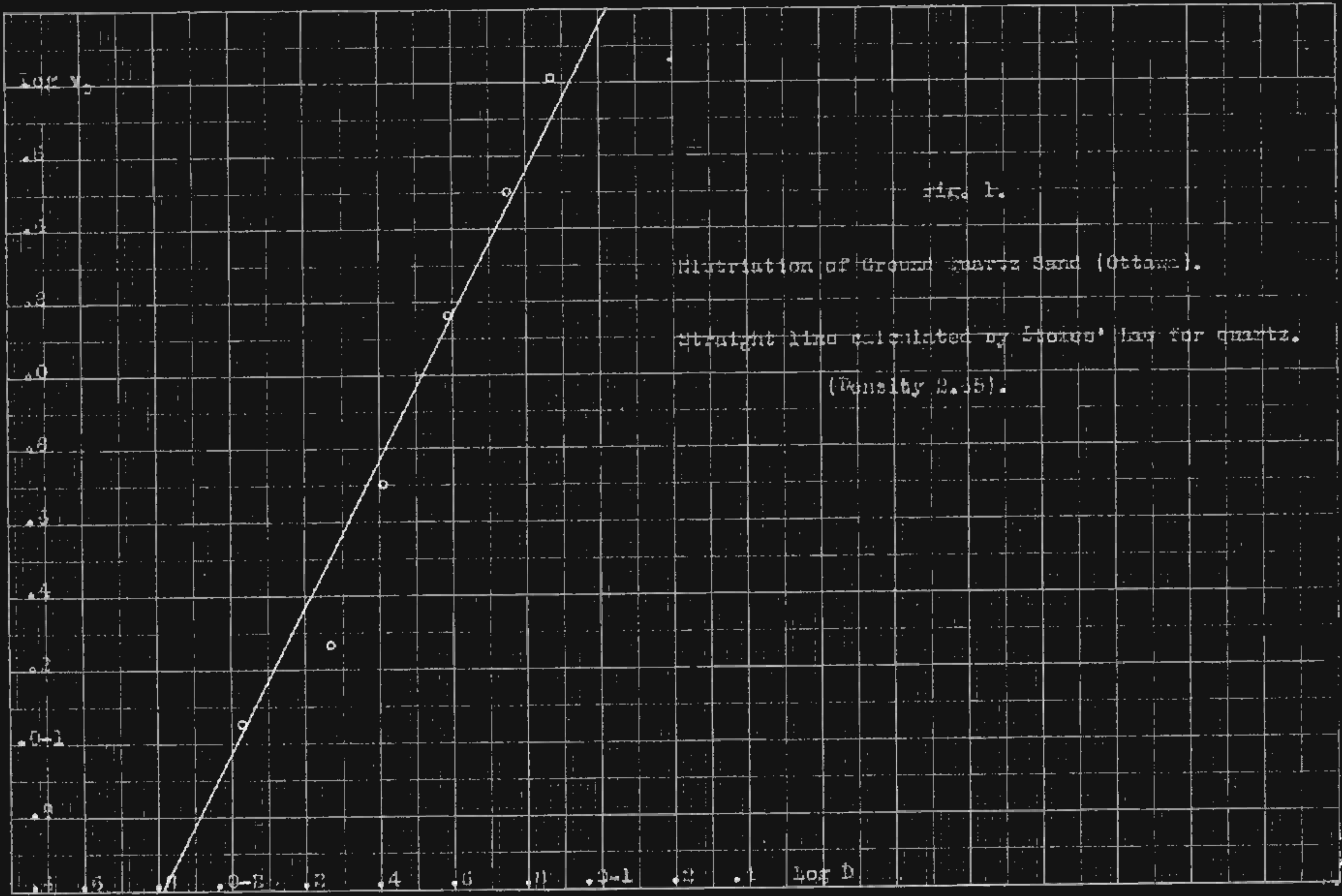


Fig. 1.

Elutriation of Ground Quartz Sand (Ottawa).

Straight line calculated by Stokes' Law for quartz.

(Density 2.65).

These measurements did not include the largest nor the smallest diameters of any one group as tests had proven that an "average" diameter is a factor too much depending on the personal qualities of the observer and therefore did not check with the corresponding velocity when plotted according to Rittinger's or to Stokes' Law. But another consideration led to satisfactory results.

Suppose a sample of quartz sand of a density of 2.65 was elutriated at a flow rate of, say, v_o = .152 mm per sec. This velocity corresponds, as shown in Table I, to a particle size of D = .013 mm. After complete elutriation at this rate, i.e., after all particles smaller than .013 have been removed, and the overflow becomes perfectly clear water, the velocity is changed to the next rate, say, v_o = .325 mm/sec. This rate of flow corresponds to a diameter of D = .019 mm. Now it is obvious that the residues of this section contain all of the material larger than .013 and smaller than .019 mm. Thus it includes grains of .0131, .0132, .0133, .0134, etc.; an innumerable number of different diameters between two limits. The problem resolves itself into deciding which one is the representative diameter of this group. According to Stokes it is the diameter of those particles which at the corresponding terminal velocity of the upward rising water current are kept in suspension. But it is very important to note that this holds only for

perfect spheres, which never occur in the ore dressing practice. Since the actual particles have more or less irregular forms which resist the water current more than a ball of the same hydraulic value, the diameter determined by Stokes' Law may be assumed as the diameter of that particle which can just overflow the edge of the elutriator at the constant terminal velocity. The practical results approve this assumption.

In the report of analogous tests at the Intermountain Station of the Bureau of Mines, which will probably be published in short time, it is said in discussing Stokes' formula in connection with elutriation:

> "If a value of v is taken as the velocity of the rising current, then D is the diameter of a quartz particle that will remain suspended. To overflow this particle a stronger upward stream will be required, which in turn will overflow still coarser particles that may be favorably situated. An elutriator or any classifier as a sizer leaves much to be desired, but it is the best that can be done on fine sizes. To overflow them a certain size a somewhat stronger current is needed than indicated by Stokes' Law.-----"

A table follows containing results of elutriation of a quartz sample, for each elutriation product an "average size" being given. Then it is continued:

"These results would indicate, if Stokes' Law holds, that the upward flow used was not sufficiently strong to overflow the coarser particles in the time alloted, or that the fine material from the previous overflow was not thoroughly washed out."

The definition of the terminal velocity according to Stokes is given correctly in the article cited as relative velocity of the particle which will "remain in suspension" at a certain rate of flow. On the other hand, as already mentioned above, one can forego the theoretical accuracy on account of the practical results.

It was found that, when the elutriator was running for an extremely long time (over night) with constant velocity, practically no particles remained in suspension, but the water in the cylinder became clear. This can be explained by either of two possibilities:

The most probable one is that, since the mineral grains, far from being perfect spheres, often show the form of plates, two dimensions of which are large at the expense of the third one, they offer a relatively large plane to the water current and can overflow, although their hydraulic value would require their remaining in suspension. There is, furthermore, a small percentage of particles only one dimension of which is extremely large in comparison with the two other ones. These grains are

not likely to develop sufficient resistence to the water current and settle again on the bottom of the classifier.

Another explanation for the absence of particles in suspension after long running might be that the uprising water current is very much disturbed by the rotating impeller shaft resulting in higher inner friction of the particles and water, and in consequence a partial compensation of the lifting effect.

These practical considerations were the reasons for selecting the "largest" and not the "average" diameter as more nearly corresponding to Stokes' Law. The determination of an average diameter, which of course must include the largest and smallest diameters and also be based on the relative frequency of occurrence of the different sizes, proved to be too much influenced by the inaccuracies of the classifying method and by the personal qualities of the observer.

In comparing the above: "To overflow then a certain (average) size a somewhat stronger current is needed than that indicated by Stokes' Law", with the results obtained in this investigation, which showed that the largest diameters checked well Stokes' formula, it can be said that both investigations carried on independently from each other came to the same practical conclusion.

Therefore the microscopic measurement of the quartz, and

in consequence all other samples elutriated, included only the largest particles of each section, that is to say, the largest particles which were present in fair percentage. To exceedingly large grains no attention was paid since they consisted of extremely flat plates and, although their hydraulic value agreed with that of the whole group, the dimensions were too disproportionate.

The logarithms of the diameters thus obtained were plotted against the logarithms of the corresponding velocities, and Fig. 1. shows that the points lie very closely to the ideal curve calculated in Table I.

Fig. 2 illustrates results of the elutriation of flotation concentrates of the American Zinc Co., Mascot, Tenn. The ideal curve has been determined in the same way as for the quartz sample based on a specific gravity of the concentrates of $\delta = 3.75$. This value was calculated by the method of the moisture flask.

While the quartz sample was minus 200 mesh, the zinc concentrate sample was prepared differently. A part was left unscreened and another part was screened through 400 mesh. The course of the curve of the unscreened concentrate shows in the larger sizes a deviation of the practical results from the ideal curve. This phenomenon, which already has been observed by Richards, Stadler, and others, indicates that Stokes' Law has no

unlimited application in this range, but Rittinger's Law does not cover accurately this interval either. We have therefore to assume that between the range covered by Stokes' formula

$$v_o = K (\delta - 1) D^2$$

and that covered by Rittinger's formula

$$v_o = C (\delta - 1) D$$

an interval exists, which must be controlled by another formula. Taggart gives for this range an equation of the general form

$$v_o = c.D^k$$

where c and k vary with the nature of the minerals.

Taggart, A.F., Handbook of Ore Dressing, 1927, Section 6. John Wiley & Sons, New York. page 552.

But as this range was out of the limit of the investigations in question no further attention has been paid to proving or disapproving the validity of the above formula.

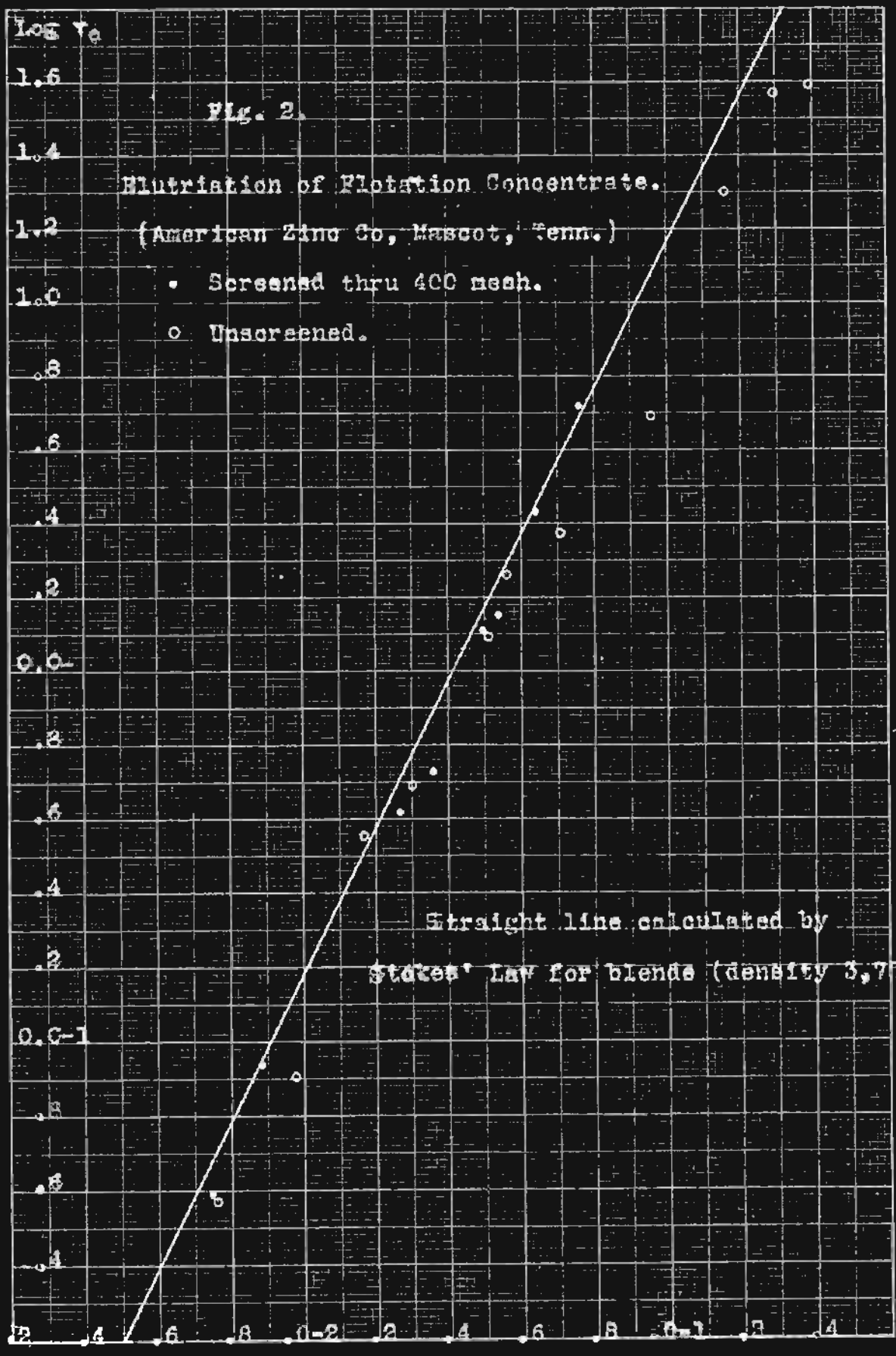


Fig. 2.

Elutriation of Flotation Concentrate.

(American Zinc Co, Mascot, Tenn.)

• Screened thru 400 mesh.

o Unscreened.

Straight line calculated by

Stokes' Law for blende (density 3,75)

PREVIOUS EXPERIMENTAL WORK.

By no means was this the first time that fine mineral particles below the screening range were classified. Elutriation methods using different apparatus have been familiar to the ceramic engineer for many years. Good ceramic products require constituents of very uniform and, usually, of extremely fine grain size. These requirements can be met easily by using simple hydraulic classification.

But with regard to the investigation of ore slimes and other fine materials of the ore dressing practice the research work carried on by the Bureau of Mines seems to be one of the first of its kind. The only valuable and detailed information of earlier laboratory work in this subject was found in a Bulletin of the (English) Institution of Mining and Metallurgy.

Stadler, H., Grading Analysis by Elutriation.
The Institution of Mining and Metallurgy, London.
Bulletin 104, (1913).

The author of this paper discusses very comprehensively the results of his elutriation tests with South African Rand ores. He used an elutriator similar to that generally used in agricultural laboratories for mechanical

analysis of soils, which is known as "Schoene"-Elutriator. Since this type of elutriator willbe taken up later, a description will not be given here.

Stadler was led to his elutriation work by the fact, already mentioned, that about 15 years ago the manufacture of an accurate 200 mesh screen was practically impossible. He therefore used as feed for the elutriator a minus 150 mesh Rand ore. He was confronted with more favorable general conditions for hydraulic classification than were those which determined the tests with which this paper is dealing. As it will be seen later, the difficulties of the elutriation increase with the increasing fineness of the material to be classified.

R.H.Richards has also done work on the velocity of mineral grains falling in water; but his data are valuable only for comparison as most of his investigations were done on coarser particles of uniform chemical composition, and details of his elutriation method and apparatus are not given.

Richards, R.H., Ore Dressing. Second Edition 1908. vol.I, chapter XII, pages 464-475; vol.III, chapter XXXIII, pages 1420-1434.

At the Intermountain Station of the Bureau of Mines in Salt Lake City, Utah, contemporary research work on

the same subject has been carried on. The results of this investigation were not available at the time the tests in Rolla were run.

DESCRIPTION OF THE ELUTRIATOR.

The original elutriator was designed at the Intermountain Station of the U.S.Bureau of Mines. But several changes in it were made during the course of this investigation. Its design is based on the same principle as all hydraulic classifier, but the arrangement in some parts differs considerably from other elutriators.

As seen in Fig.3, the elutriator consists of a vertical glass cylinder, 60 cm high and 50 mm inside diameter (D). The lower end is terminated by a cone. Inside the cylinder is a glass-tube shaft or rotor, on the lower end of which is a rubber impeller, and on the upper end of which is a bearing and a pulley. The shaft and the impeller are rotated by electric motor at 60 r.p.m. The outer diameter of the impeller shaft is d = 18 mm. Thus the entire free area available for the upward rising water current is

$$A = (D^2 - d^2)\frac{\pi}{4} = 1710 \text{ sq.mm.}$$

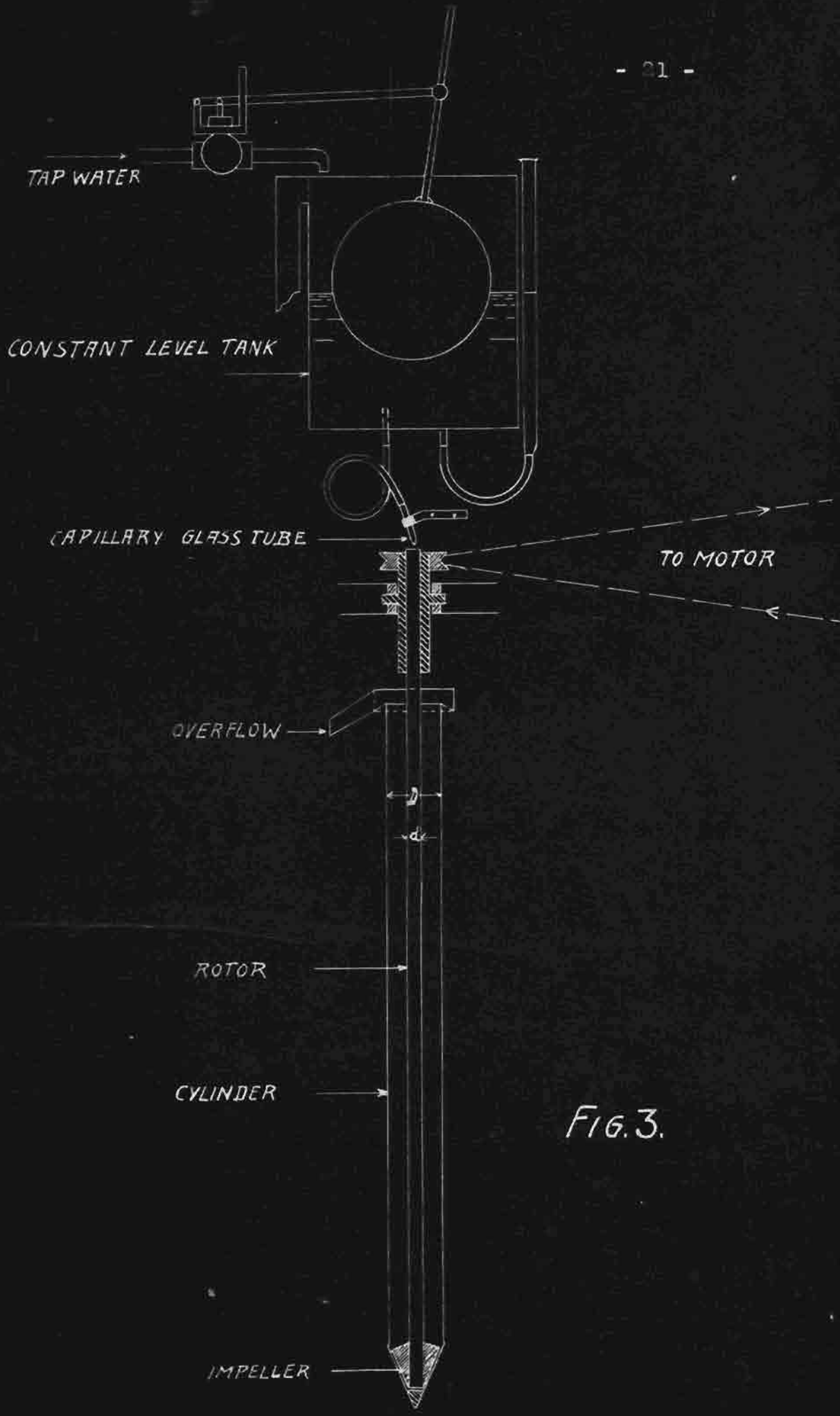

TAP WATER
CONSTANT LEVEL TANK
CAPILLARY GLASS TUBE
TO MOTOR
OVERFLOW
D
d
ROTOR
CYLINDER
IMPELLER

FIG. 3.

A circular overflow launder is provided on the top of the cylinder to catch the overflowing slime. The water for the classification is stored in a zinc-lined tank of ten liters capacity. An automatic valve keeps the water level in the basin fairly constant by opening and closing the connection to the tap water. In order to observe occasional changes in the water level a second outlet on the tank was provided and connected with a vertical graduated glass tube.

In contrast to other elutriators the water is introduced to the bottom of the apparatus through the shaft of the impeller. This arrangement caused trouble during almost the entire period of work as it was very hard to connect the outlet of the water tank satisfactorily with the rotating glass tube, and to furnish, at the same time, a well working regulator to keep the velocity of the water current at a constant rate for long periods of time. In the original elutriator a diaphragm valve was used for this purpose. But when the finest slimes were elutriated, i.e., when the smallest rate of water was employed, it was practically impossible to keep the velocity constant. A regular globe valve, used as a substitute, did not work well either, and even when a simple clamp was applied to the rubber tubing the velocity re-

gulation was poor. Finally the most satisfactory control was obtained by the use of capillary glass nozzles with definite openings for the various rates of flow.

An essential requirement for the successful use of these glass tips is a uniform water supply as regards cleaneness from impurities and temperature. To satisfy the first condition the tank must be built of non-corrosive material. Zinc proved best. A capacity of ten liters provided water of constant temperature at least for the smallest rates of flow during which the dangers from temperature variations are greatest.

Of course the high fragility of the capillary glass tubes is disadvantageous. But the substitution of metal tubes would require the exclusive use of distilled water, since minute layers of impurities, which collect in the tips of the capillary tubes and slowly lower the rate of flow, could not be seen. The nozzles were kept clean by washing in dilute sulphuric acid.

The following table shows the capacity of glass tubes which were used successfully in most of the tests:

Nr.	Rate of Overflowing Water	Velocity of Water in Cylinder
1.	.059 cc./sec.	.0345 mm/sec.
2.	.175 "	.102 "
3.	.623 "	.364 "
4.	.864 "	.505 "
5.	2.22 "	1.295 "
6.	3.18 "	1.860 "
7.	4.00 "	2.340 "

PROCEDURE.

A. PREPARATION OF THE SAMPLE.

The preparation of a sample consisted, first of all, in screening as far as possible. From the difficulties already mentioned in handling material of extreme fineness, it might appear inadvisable to continue the screen analysis beyond, say 200 mesh, thereby producing a very fine feed for the elutriation. At the Intermountain Station the preliminary screening was carried on only through 200 mesh; whereas in this investigation, the elutriation feed was generally a minus 400 mesh product. The reasons for this fine screening will follow:

A fraction of an elutriated mill product consists of particles of different sizes, depending on the specific gravity of the mineral constituents. Usually we will find small ore grains (galena, blende, pyrite) with larger gangue particles in the same section. But in an investigation of flotation products this variety in grain size is not important, since good flotation concentrates usually contain little gangue material and good flotation tailings contain relatively few ore particles. On the other hand poor concentrates or poor tailings contain a large percentage of particles composed of combined ore and gangue in various proportions.

A sample as uniform in size as possible will be best fitted for the analysis by elutriation. For this purpose most of the samples used in the tests to be discussed were sized in the Tyler scale down to 400 mesh. By this method all the material larger than .038 mm was removed from the elutriator feed. Thereby also the time needed for a complete grading analysis was shortened, because a smaller sample gave in each division sufficient material for chemical analysis.

The amount of material used for one run was determined by different factors. The capacity of the elutriator and the accuracy of the results demanded a sample as small

as possible. On the other hand the endeavour to determine the correct total amount of metal of each overflow rate required a definite minimum of solids in each cut. These components varying with the mineralogical and structural character of the flotation products resulted in samples of 25 to 50 gm of dry material.

At first the extreme fineness of the samples caused considerable trouble by coagulation. The particles of almost colloidal grain size tended to unit into larger masses when agitated in water. This difficulty had to be overcome as the elutriation of flocculated material gives an absolutly wrong picture of the relations of mineral and size throughout the flotation products. It decreases the solid material in the finest overflow in favor of the overflows of higher hydraulic values. After unsuccessful tests with alkalin hydroxides, ammonia, etc. the use of .1% solution of gum arabic proved best as a deflocculating agent. The feed sample was throughly mixed with about 300 cc. of this solution in a separatory funnel and left here for at least 12 hours. The separatory funnel permitted an easy introduction of the conditioned sample into the cylinder of the elutriator. In general 300 cc. of gum arabic solution developed enough deflocculating effect for at least the first part of the test. A later tendency of coagulation could be overcome by

adding a few little lumps of gum arabic in the inner glass tube without stopping the test.

B. ELUTRIATION OF THE SAMPLE.

After conditioning the pulp in the manner described the rotor was started and the material poured into the elutriator. In order to give the mineral particles a rough pre-classification while introducing the sample, a strong water flow was used in the elutriator until the glass cylinder was filled to about three-forth of its capacity. Then the water flow was reduced to its regular first (slowest) rate. By this method the finest particles were prevented from settling on the bottom of the elutriator below the outlet of the inner water tube.

Glass beakers of two liters capacity were found satisfactory for catching the overflowing pulp. For the last rates where relatively small amounts of coarse material were carried over by large quantities of water, bigger vessels such as enamel pans and buckets are better fitted.

In general it can be stated that the time required for a complete elutriation test depends chiefly upon the velocity of the water flow at the start, since the first rate of flow takes the greatest percentage of the entire time of the run. When starting with a velocity of .035 mm

per sec. which equals an overflow of .06 cc. per sec. the time for elutriating a 25 gm sample of minus 400 mesh material requires from 8 to 12 hours, the first rate of overflow taking 40 to 60% of this time. The physical composition of the product had a greater effect upon the time than the weight of the material tested (25 or 50 gm).

C. RECOVERY OF THE SOLID RESIDUES.

Gum arabic, although favorable as a dispersing agent, was disagreeable in its effect after the elutriation was finished. It was found impossible to settle out completely the solid particles from the overflow of smallest hydraulic value. The finest material, less than 5 microns in diameter, remained partly in suspension. It was found that from this first overflow after a settling time of about one day, 90 to 95% of the solids settled out, the amount differing somewhat with the character of the product, while the rest remained in suspension even after several days.

Since the finest particles are often the most important, and since even for large tonnages of mill products only 25 gm are taken as a sample, it is necessary to recover as much as possible of the suspended solids and to reduce losses to a minimum. In order to do this many of the ge-

nerally known coagulating agents were tried. Some acids seemed to be good flocculators, but as their maximum efficiency is dependent on a very definite concentration with respect to the amount of solids, a factor extremely variable in an elutriated overflow, none of these coagulating reagents proved as satisfactory as might be expected.

A relatively simple means of bringing the solid particles out of suspension was finally found in the centrifuge. The advantage of this apparatus is that the concentration of the suspension, the reagents used for dispersion, and the hydrogen ion concentration play very little part. A practically complete separation of two liters of suspension containing mostly minus 5 micron material could be accomplished in an electric centrifuge of 2400 r.p.m. speed with four 50 cc. glass tubes in about 2 1/2 hours. This time could be shortened by using the centrifuge with a crown for larger tubes.

Before centrifuging the suspensions of the finest overflows the losses of residues amounted as high as 7 to 9% by weight. This was cut down by the use of the centrifuge to about 1 to 1.5%. A small loss in this very fine size seems to be unavoidable, and is chiefly due to the difficulty of completely removing the dried solids from the beakers. Even by very careful use of a soft brush the for-

mation of dust is hardly avoidable, and a certain amount of material cannot be recovered at all because of its hygroscopic behaviour. In some cases it was found advisable to wash out the finest material with a small amount of alcohol, which was afterwards evaporated.

At the Intermountain Station where also gum arabic is being used as dispersing agent, a good precipitating effect has been found in the addition of copper sulphate and ammonia to the suspension. The copper hydrate precipitate formed carries down all dispersed material and is then dissolved in Hydrochloric acid.

After the clear water had been poured out of the settled beakers, or the suspension had been centrifuged, the solid residues were dried. Here again it proved advantageous to have used but the minimum amount of gum arabic for conditioning the pulp before the elutriation. A large amount of this electrolyte in the residues tended to form dark brown crusts on the bottom of the vessel thus rendering a complete recovery of the solids more difficult.

D. MICROSCOPIC EXAMINATION.

The microscopic examination was carried on with a regular metallurgical microscope using an eyepiece micrometer and transmitted light. It consisted of single measurements of six different grains in a repre-

sentative sample of each fraction. The mean value was taken as the representative diameter of the product. No attention was paid to particles two diameters of which were greatly different.

Some difficulty arose in measuring the finest elutriated overflow because the minute particles of the highly hygroscopic powder were hard to separate on the slide. Alcohol was used as a dispersing agent. In certain cases the conditioning of the sample with a solution of Canada balsam in xylol similar to that suggested by Schneiderhöhn proved best.

Schneiderhöhn, H., Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen und Aufbereitungsprodukten besonders im auffallenden Licht. Berlin 1922. page 61.

The photomicrographs, Fig.4 to 11, show fairly well the uniformity in grain size of various elutriation products, which is in striking contrast to the irregularity of grain size in the unelutriated minus 400 mesh products, Fig.12 and 13. The samples are Tri-State flotation tailings, except in Fig.11 and 13, which show Ottawa quartz and South East Missouri dolomite.

The hydraulic values represented by the photomicrographs are:

Fig.	4	above 3.22	cc./sec. (residue in spigot)
"	5	3.22	"
"	6	2.52	"
"	7	1.29	"
"	8	.50	"
"	9	.18	"
"	10	.12	"
"	11	.11	"

E. CHEMICAL ANALYSIS.

The dry residues were weighed and assayed. The chemical analysis is the deciding factor in determining the size of the sample to be graded. When the products are low in metal content about two gm of dry residue is needed for each assay. When the metal content is exceedingly low, still larger fractions are required. The Mascot flotation tailings assayed in the composite sample only 0.092% Zn and required at least 5 gm of solids in each portion for exact results. This necessitated using a large elutriation sample. On the other hand samples of one gm were sufficient in the case of elutriated concentrates.

Fig.4

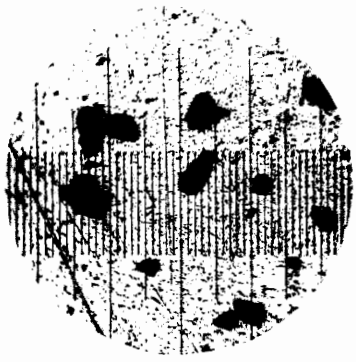


Fig.5

Fig.6

Fig.7

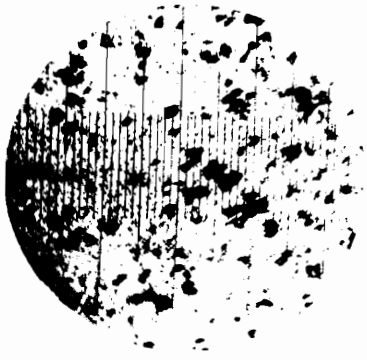


Fig.8

100:1

Fig.9

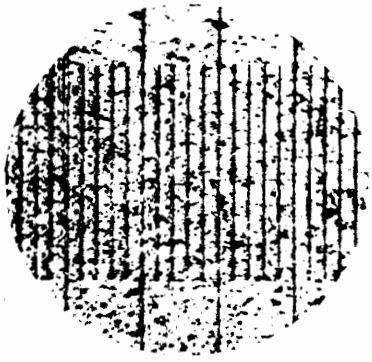


Fig.10.

200:1

Fig.11.

Fig.12.

100:1

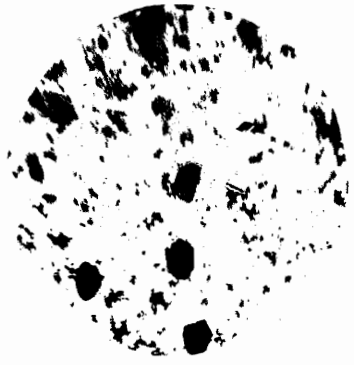


Fig.13.

Fig.15.

Ottawa Quartz

- 400 Mesh.

MATERIALS TESTED.

In as much as other experimental work was being done on mill products from the South East Missouri Lead Belt and the Tri-State Zinc District flotation products from these districts were tested by elutriation. In addition crushed (Ottawa) quartz sand in the fundamental tests and flotation products from Mascot, Tenn. were also elutriated.

In one case flotation tailings which were produced in the laboratory were tested in order to show the changes in mineral distribution by improved flotation method.

DISCUSSION OF RESULTS.

The results of tests are shown in the accompanying tables. Table II illustrates the results of screening various products through the 400 mesh screen. (page 34)

From this table it can be seen that the minus 400 mesh part of flotation tailings assays higher in metal than the total tailings, and consequently higher than the plus 400 mesh part. For concentrates the opposite is true: The plus 400 mesh fraction assays higher than the minus 400 mesh fraction.

Elutriation enables separations to be made far beyond the 400 mesh point. The results of complete grading tests

are given in the Tables III, IV, and V.

Table II.

Minus 400 Mesh Material in Samples.

Name of Product	Per Cent Weight in - 400 Mesh Product	Per Cent Metal in		Total Per Cent Metal in -400 Mesh Product
			Complete Sample	
Bonne Terre Flot. Tails	52.5	.21 Pb	.125 Pb	81.9
Tri-State " "	34.6	3.32 Zn	1.94 Zn	59.1
" " Feed	31.2	8.30 Zn	6.19 Zn	42.2
" Lab. " Tails	29.7	1.41 Zn	.77 Zn	55.9
Mascot Flotation "	32.5	.15 Zn	.15 Zn	53.2
" " Conc.	27.2	57.91 Zn	58.82 Zn	27.1

Table III.

Elutriation Test of Flotation Tailings Made From a Missouri Dolomite Lead Ore.

Grain Size	Per Cent Weight	Assay Per Cent Lead	Per Cent Total Lead
+ 100 Mesh	2.3	.045	.8
- 100 Mesh + 150 "	7.4	.052	2.8
- 150 " + 200 "	15.4	.058	6.6
- 200 " + 270 "	8.0	.045	2.6
- 270 " + 400 "	14.3	.051	5.4
- 400 " + 25 Microns	11.8	.066	10.4
- 25 Micr. + 20 "	5.7	.043	3.4
- 20 " + 5 "	22.2	.090	27.5
- 5 "	12.9	.230	40.5
	100.0	.136	100.0

Table IV.

Screen and Elutriation Test on Flotation Feed and Tailings from a Tri-State Zinc Ore.

Grain Size	Per Cent Weight			Assay Per Cent Zn			Per Cent Total Zn		
	Feed	Mill Tailings	Lab. Tailings	Feed	Mill Tailings	Lab. Tailings	Feed	Mill Tailings	Lab. Tailings
+ 48 Mesh	1.2	2.7	1.5	1.58	0.97	0.53	0.3	1.3	1.0
- 48+ 65 "	6.6	6.6	10.3	1.41	0.84	0.39	1.5	2.8	5.4
- 65+100 "	19.1	15.7	22.5	2.01	0.79	0.39	6.3	6.4	11.7
-100+150 "	14.0	11.6	11.6	2.57	1.39	0.52	5.9	8.3	8.0
-150+200 "	8.4	7.6	8.1	6.99	2.00	0.63	9.6	7.8	6.8
-200+270 "	10.2	9.9	8.9	10.34	1.53	0.54	17.2	7.8	6.4
-270+400 "	9.3	11.3	7.4	11.24	1.12	0.49	17.1	6.5	4.8
-400+ 25 Microns	2.0	0.3	9.2	16.08	2.77	0.75	5.8	0.6	9.3
- 25+ 15 "	9.5	8.8	3.6	9.60	1.40	0.71	14.9	7.8	3.6
- 15+ 10 "	10.0	14.3	7.5	6.68	2.05	0.96	11.0	18.6	10.3
- 10+ 5 "	3.6	1.8	---	6.92	4.00	---	4.1	4.3	---
- 5 "	6.1	9.4	9.4	6.36	4.65	2.43	6.3	27.8	32.7
Total	100.0	100.0	100.0	6.14	1.94	.75	100.0	100.0	100.0

Table V.

Screen and Elutriation Test on Flotation Concentrates and Tailings from a Tennessee Zinc Ore.

Grain Size	Per Cent Weight		Assay Per Cent Zn		Per Cent Total Zn	
	Concentr.	Tails	Concentr.	Tails	Concentr.	Tails
+ 35 Mesh	0.6	1.3	55.65	0.20	0.6	2.8
- 35+ 48 Mesh	3.4	4.4	54.26	0.09	3.2	4.4
- 48+ 65 "	7.6	7.9	54.76	0.05	7.2	4.3
- 65+100 "	21.5	15.1	57.04	0.06	21.1	9.8
-100+150 "	18.2	11.1	59.62	0.05	18.7	6.0
-150+200 "	10.8	8.1	60.31	0.05	11.2	4.4
-200+270 "	4.3	10.9	58.63	0.07	4.3	8.3
-270+400 "	6.4	9.0	60.31	0.07	6.6	6.8
-400+ 35 Microns	9.3	3.9	58.31	0.16	9.3	6.8
- 35+ 25 "	3.4		58.22		3.5	
- 25+ 15 "	8.1	9.4	58.46	0.06	8.2	6.1
- 15+ 10 "		4.9		0.09		4.8
- 10+ 3 "	6.4	5.5	56.44	0.21	6.1	12.5
- 3 "		8.5		0.25		23.0
Total	100.0	100.0	58.10	0.092	100.0	100.0

When we compare the results given in the Tables III, IV, and V it is striking that the sections on the boundary between screening and elutriation assay high in metal. That indicates that the coarsest elutriation product, or the last overflow from the elutriator, representing in general but a small percentage by weight, is very rich in metal.

This can be explained by the fact that a commercial hydraulic classifier usually also gives a relatively rich product in the first spigot, which classifies with the highest velocity of the water current, if a pre-screened material is fed. In this product of highest hydraulic value the differenc between screen classification and grading by elutriation is greatest. The following consideration shows the mechanical explanation.

In considering a complete series of elutriation products of a mill sample we find in each section of equal hydraulic value two different types of particles: Relatively large gangue particles and relatively small ore particles. Screening the sample before elutriation through a definite screen means therefore removing a part of the large gangue particles from the group of highest hydraulic value. Consequently the last overflow product of any elutriation the feed of which has been screened will assay high

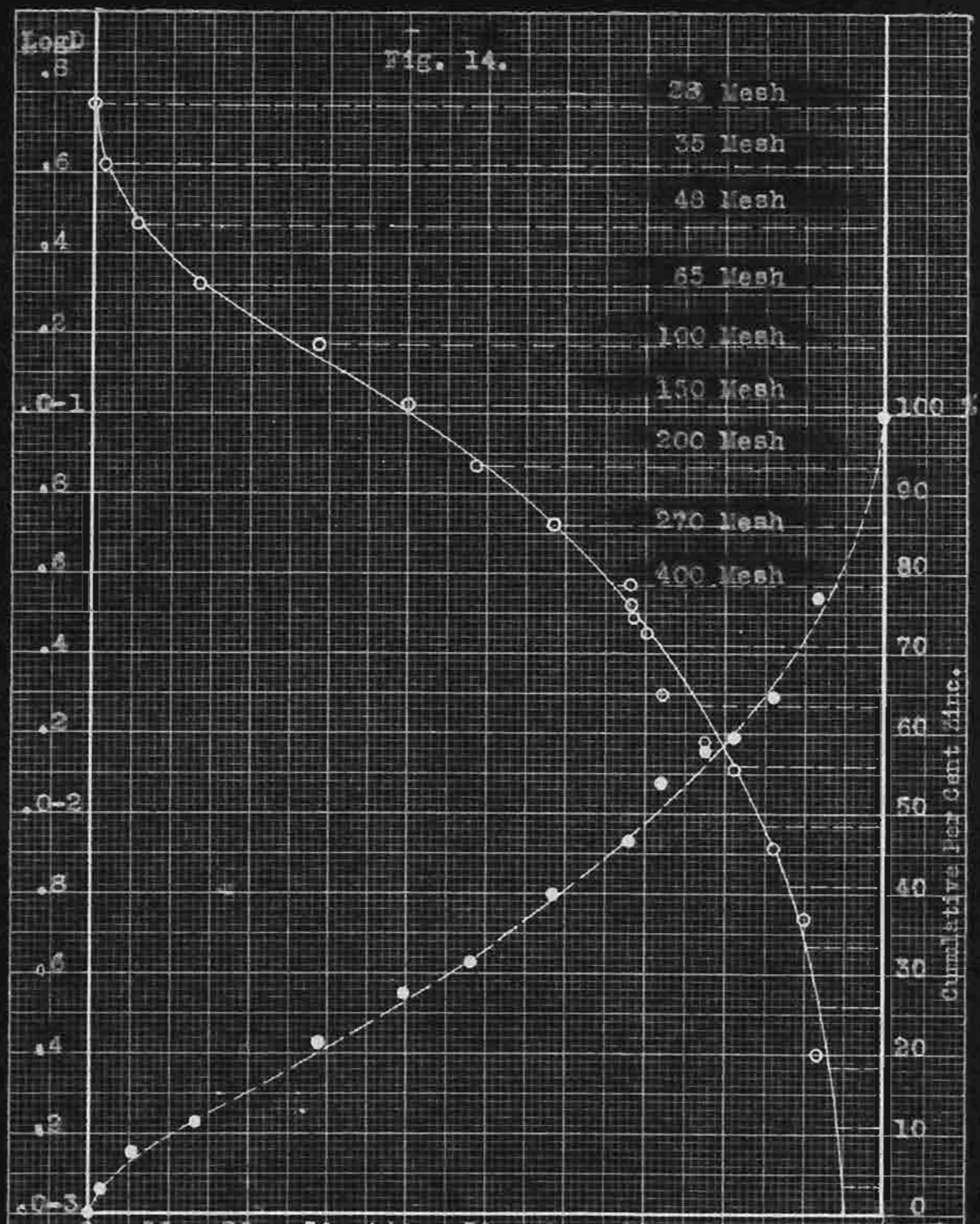
in metal.

It should also be noted that the minus 5 micron fractions of the tailings assay highest in metal and contain the largest percentages of the total metal of all the fractions.

In contrast, the minus 10 micron fraction of the concentrates is relatively low in metal content and carries only a small amount of the total metal. The example given may be slightly exaggerated since coagulation and incomplete separation reduced the amount of the finest material recovered.

In Fig.14 the results of a complete size analysis including screening and elutriation is plotted in the cumulative percentages. The values obtained in the practical test form two faily regular curves. A small irregularity can be noted in the transition zone between finest screening and coarsest elutriation products where, as explained above, the difference between screening and elutriation is particularly great.

In considering the results it can be stated that the elutriator as developed in the course of these tests gives good results which are in general free from objections. There can be of course different opinions as to the accuracy required for the purpose in question. On all procedures where by skill and careful manipulations avoidable inaccuracy can be eliminated, the utmost care must be maintained. However there are some inherent errors based on the



Screen and Elutriation Analysis of Flotation Tailings.
(Mascot, Tenn.)

special construction of the elutriator used which cannot be avoided, but can be reduced to a minimum.

The whole series of tests has shown that a chief source of trouble is the introduction of the water through the rotating shaft of the impeller. Here two factors cannot be brought into agreement. They are
(1) to provide between the end of the inner glass tube and the bottom of the elutriator a space wide enough to make possible elutriation of the coarsest particles, and
(2) at the same time to have the space as small as possible to force the water current through the lowest layers of the sample to be classified.

It could be seen from the report of the experimental work at the Intermountain Station that this arrangement did not work very satisfactorly in those investigations either, but the effect was probably not so great as in the tests at Rolla, where elutriation was done on samples of minus 400 mesh fineness in 6 or 7 steps as compared with minus 200 mesh material graded in 3 steps in Salt Lake City.

Furthermore the ratio of the diameter of the elutriator cylinder to that of the impeller shaft does not yet seem to be right. The ratio of the present arrangement is 50:18, i.e. the diameter of the cylinder is not yet three times as large as that of the smaller tube. Observations on the running elutriator showed that the

relatively big inner tube causes the upward rising current to form whirlpools resulting in inaccurate classification of the sample. This trouble can probably be reduced by either increasing the diameter of the elutriator cylinder or by decreasing that of the impeller shaft or better by changing both diameters respectively.

The difficulties in maintaining a water current constant for long time at slow rate had been mentioned in the description of the elutriator. Perhaps some other type of water feeder can be designed to give more satisfactory regulation.

Considering all these difficulties it is appearent that the statement that the apparatus gives good results does not hold unless utmost care and watch are used, a condition that may be called burdensome and uneconomic with regard to the long time required for each test. Here the author cannot help asking if not a classifier of less complicated type would give the same, maybe better, results while less supervision is required.

The tests Stadler has reported on were performed in an elutriatorwhich is known as "Schoene-Elutriator". On this design the mechanism for stirring up the sample is entirely missing. That is possible as the water current enters the classifier on the lowest point of the cone through a glass cock from without. This arrangement pro-

vides an uniformily rising current, which cannot be disturbed by mechanical agitation of any kind. Since Stadler does not mention any difficulties in regulating a constant flow, this trouble seems also to be overcome. He used for changing the rates of flow in steps constant for all tests a piezometer, the arrangement of which can be seen from the sketch inclosed (Fig.16). Stadler says as regards uniformity of the smallest velocity of the classifying water current:

"The displacement of the finest slime takes a long time, but as the level in the piezometer keeps extremely steady the apparatus can safely be left, and other work undertaken in the meantime."

As there was no chance of trying an elutriator of the type Stadler used for his tests the design of an elutriator as suggested in Fig. 16 will be open to criticism. But it seems probable that at least three factors which caused much trouble and inaccuracy in the present arrangement, can be improved if not absolutely eliminated. They are

(1) The introduction of the water on the lowest point of the elutriator results in classifying the entire sample without leaving a small layer of unclassified material in the cone of the classifier.

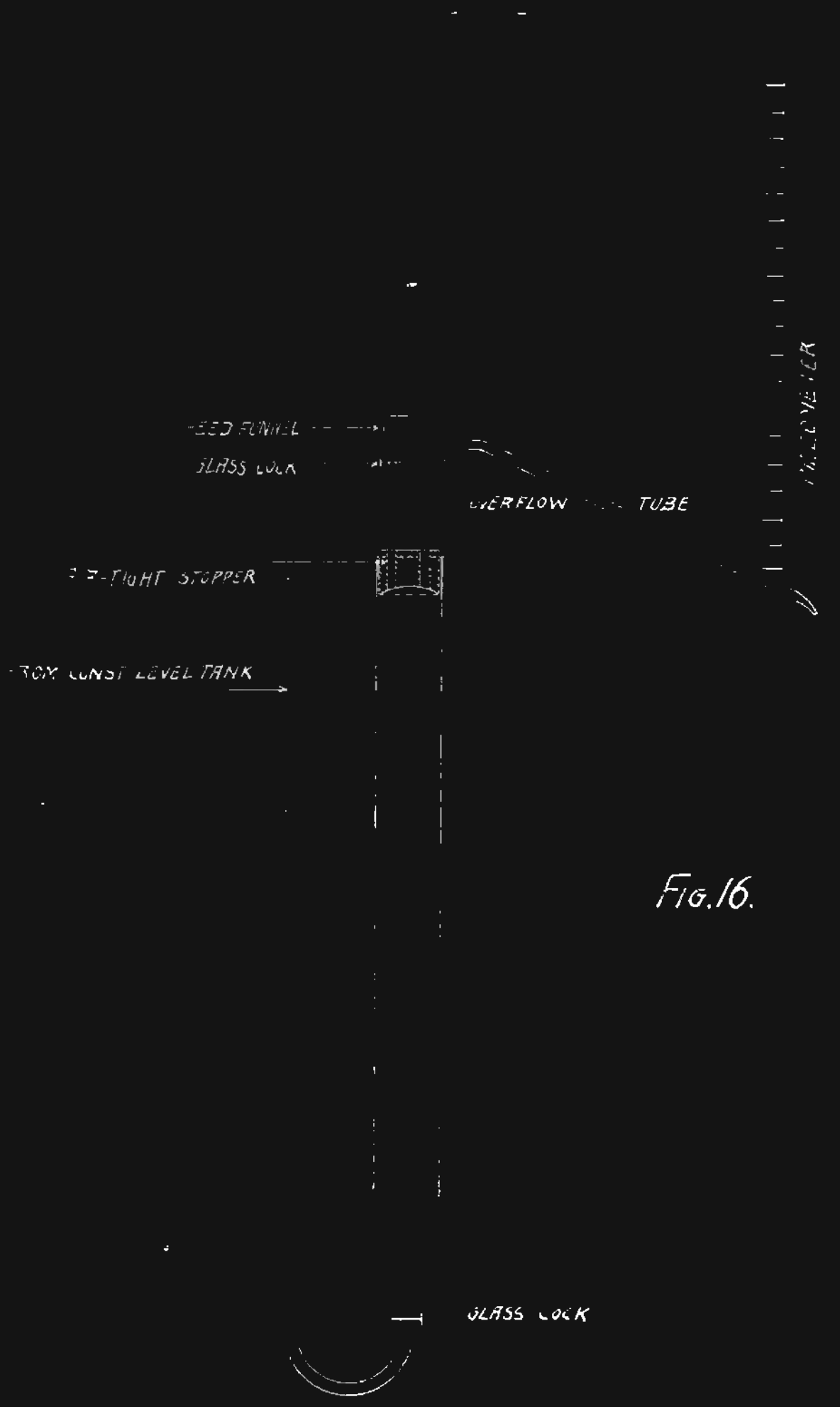

FEED FUNNEL
GLASS LOCK
OVERFLOW TUBE
AIR-TIGHT STOPPER
CONST LEVEL TANK
GLASS LOCK

Fig. 16.

(2) Omission of mechanically moved parts provides an undisturbed water current (except unavoidable friction on the walls of the cylinder).

(3) A well lubricated glass cock cooperating with the piezometer gives a chance of easy regulation of the same and constant rates of flow for any tests.

C O N C L U S I O N S .

In summarizing the results of this research as regards its usefulness for general flotation practice special attention might be paid to the fact that in all flotation tailings the highest percentage of the total metal content was found connected to the finest particles, minus 5 microns in fineness. In flotation concentrates the total amount of metal in this size range is relatively small.

This phenomenon leads to the statement that the efficiency of flotation methods is limited by a lower particle size, below which the concentrate recovery decreases rapidly. Comparatively few of the minus 5 microns metal-bearing particles are recovered as flotation concentrates, most of them go into tailings. This observation justifies the tendency of modern

flotation practice of avoiding as far as possible any over-grinding.

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